1.1 Fractal and Geostatistical Metadata for Monitoring Global Change Using Remote Sensing Imagery

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1.2 Goal and Technical Objectives

- Goal:
  - Improve global change studies by facilitating access to and improving analysis of remote sensing imagery
- Objectives:
  - Develop and test software applications and techniques for characterizing spatial complexity and content of images

1.3 Technical Problem Statement

- As the geographical and temporal coverage, the spectral and spatial resolution, and the number of individual remote sensors increase, the sheer volume and complexity of available data sets will complicate management and use of the rapidly growing archive of earth imagery.
- Mining this vast data resource for images that provide the necessary information for climate change studies becomes more difficult as more sensors are launched and more imagery is obtained.

1.4.1 Technical Approach

- Evaluate the utility of content-based image descriptors such as: fractal dimension, lacunarity, and spatial autocorrelation statistics in measuring and characterizing land covers and land-cover changes with a variety of multi-scale, multi-temporal, and multi-sensor data.

1.4.2 Technical Definitions

- Fractal Dimension- A measure of image complexity, which ranges from 2.0 for a perfectly uniform image to ~3.0 for a rough texture with adjacent bright and dark areas
- Lacunarity- A measure of the gaps in a pattern depicted in an image
- Spatial Autocorrelation- A measure of the degree to which similar brightness values are clumped together or dispersed
- Wavelets- Simple cyclical functions such as Daubechies and Haar wavelets, that are shifted and scaled to represent the patterns of changing brightness values in an image

1.5.1 Data

- Satellite and aircraft imagery
  - Landsat – MSS, TM, ETM+
  - EOS – ASTER, MODIS
  - SPOT
  - AVHRR
  - Ikonos commercial satellite imagery
  - ATLAS – NASA Learjet scanner
- Four applications:
  - Urban sprawl – Atlanta, Georgia
  - Shoreline recession/storm effects- Louisiana
  - Pre/Post-fire effects – Yellowstone National Park
  - Reversion of agricultural lands to scrub/forest – Michigan

1.5.2 NASA Relevance

- Data Mining
  - Research is needed to benchmark fundamental indices of spatial complexity in remotely sensed imagery in the context of global change studies
  - Spatial Analytical Techniques
  - Not well developed for imagery, as compared to spectral methodologies
  - Can provide some of the innate abilities of human vision
- Change Detection
  - A crucial role for aircraft and space-based imaging
  - Complicated by changing technology of sensors
    - Different spatial and spectral resolutions
- Multi-scale Modeling
  - Environmental phenomena are scale-dependent

1.6.1 Accomplishments

- Java application for measuring fractal dimension
  - Lacunarity, spatial autocorrelation methods will be added soon
- Multi-date, multi-platform database of imagery
  - Atlanta, Georgia
  - Louisiana Gulf Coast
  - Yellowstone National Park
  - Michigan
- Preliminary evaluation of the utility of wavelets in characterizing remote sensing imagery
- Analysis of utility of content-based image descriptors in tracking urban sprawl

1.6.2 Preliminary Findings: Evaluations of fractal and spatial autocorrelation techniques

- Fractal dimension can be measured by a number of different algorithms
  - Although these often yield different values, each measurement method is sensitive to different image manipulation processes such as contrast stretching
  - Indices of spatial autocorrelation were found to be useful in characterizing complex images, but not simple images with low dimensionality.
  - Both fractal dimension and spatial autocorrelation indices can be applied directly to unclassified images to measure spatial complexity.

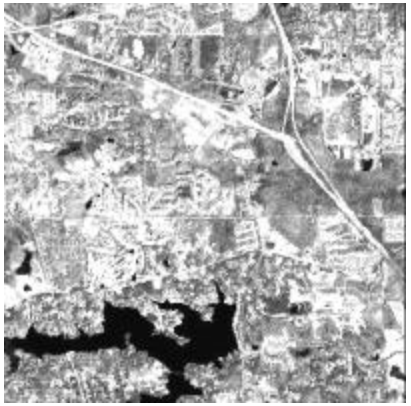
1.6.3 Preliminary Findings: Multiscale Image Characterization Using Fractal and Wavelet Techniques

- Wavelet transforms decomposed at different levels are more accurate than fractal dimension for detecting and characterizing spatial structures.
- a longer wavelet is more accurate;
  - the combination of energy signatures from multiple decomposition levels and multispectral bands leads to better image characterization results;
  - with additional fractal information, a significant improvement in classification accuracy using wavelet features over spectrally heterogeneous areas was observed.

1.6.4 Preliminary Findings:

Spatial Analysis of Urban Sprawl in Atlanta, GA

Digital Orthophoto, 1993



Landsat ETM+ Pan, 2000

- When applied to multi-platform, multi-date imagery, Moran's I index of spatial autocorrelation is closely correlated to indices of urban sprawl, such as changes in population density
- Fractal dimension has a lower correlation with changes in population density
- This allows selection of areas from a large image database that show significant alterations in land cover, such as the conversion of forest in the older photo to residential development in the later Landsat image

1.7.1 Technical Significance of Progress

- While early results indicate fractal dimension alone may not be efficient in classifying or discriminating features, we have not yet paired this parameter with the associated lacunarity index of scale-dependent gaps
- Wavelets and spatial autocorrelation measures are not independent of scale, which complicates comparisons of imagery from multiple platforms
- True fractal images are scale-independent, but real-world images are not true fractals
  - Departures from the true fractal ideal provide clues to selecting image resolution

1.7.2 Expected Impact on NASA

- Content-based image descriptors can facilitate searches of imagery databases
  - Critical to fulfilling the NASA's Earth Science Enterprise role of providing data and information needed to protect our home planet
  - Image descriptors can be added as Product Specific Attributes to EOSDIS Core Metadata Model
- Benchmarking these indices as they relate to global change studies leads to a better understanding of the implications of comparing older, low resolution imagery to newer, high resolution images
- Choosing the appropriate spatial scale for an analysis is critical to understanding how local events and processes influence the whole Earth system

1.8 Links for More Information

- Charles W. Emerson:
  - http://homepages.wmich.edu/~emersonc/
- Dale A. Quattrochi:
  - http://ghcc.msfc.nasa.gov/People/Quattrochi.html
- Nina Siu-Ngan Lam:
  - http://www.ga.lsu.edu/lam.html

1.9.1 Facilities

- GIS Research Center at Western Michigan University
  - Arc/INFO 8.1, ERDAS Imagine 8.5, MS Visual Studio, Forte for Java
- Computer Mapping Sciences Laboratory at Louisiana State University
  - Matlab, Mathematica, Arc/INFO 8.1, ERDAS Imagine 8.5; Intergraph Geomedia; MS Visual Studio; Qnet
- NASA Global Hydrology and Climate Center
  - Geographic Information Systems Laboratory

1.9.2 Personnel

- GIS/Remote Sensing Specialist
  - Burgess Howell, NASA Global Hydrology and Climate Center
- Graduate Assistants
  - Mahesh Arumugam, MS Student in Computer Science, Western Michigan University
  - Wei Zhao, former PhD graduate in Geography and Srinavas Vinnakota, PhD student in Geography, Louisiana State University

1.10 References: Research Team Publications from this Grant

- Preliminary results from wavelet-based analysis of imagery
  - Zhao, W. and Lam, N.S.-N, 2002, Multiscale image characterization using fractal and wavelet techniques, paper presentation at the 98th Annual Meeting of the Association of American Geographers, Los Angeles, CA.
- Fractal and geostatistical analysis of real and simulated imagery
  - Quattrochi, D.A., Emerson, C.W., Lam, N.-S.N., 2001, Fractal Characterization of Multitemporal Remote Sensing Data. *Modelling Scale in Geographical Information Science*, Tate, N.J. and Atkinson, P.M. eds., pp. 13-34.
  - Lam, N.S.-N, Qiu, H.L, Quattrochi, D.A., Emerson, C.W., 2002, An evaluation of fractal methods for characterizing image complexity, *Cartography and Geographic Information Science*, **29:**12, 25-35.
  - Emerson, C.W., 2002, Fractal metadata for urban change investigations, paper presentation at the 98th Annual Meeting of the Association of American Geographers, Los Angeles, CA.